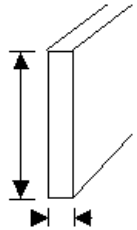
Active Vibration Damping in the Presence of Uncertainties

Travis Eisenhour	*Notre Dame*
Sam Hatchett	*Texas Tech*
Isaac Salazar	*Texas A&M*
Matthew Bement	*Mentor*

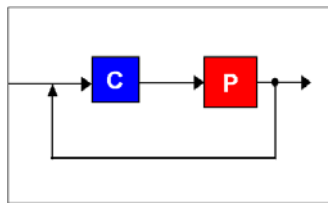
We will discuss four main areas

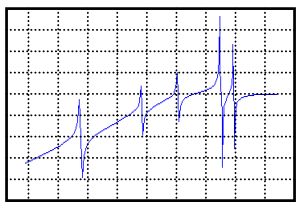
Project Description



System Behavior

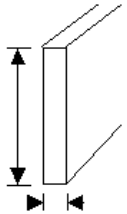
Control Methods

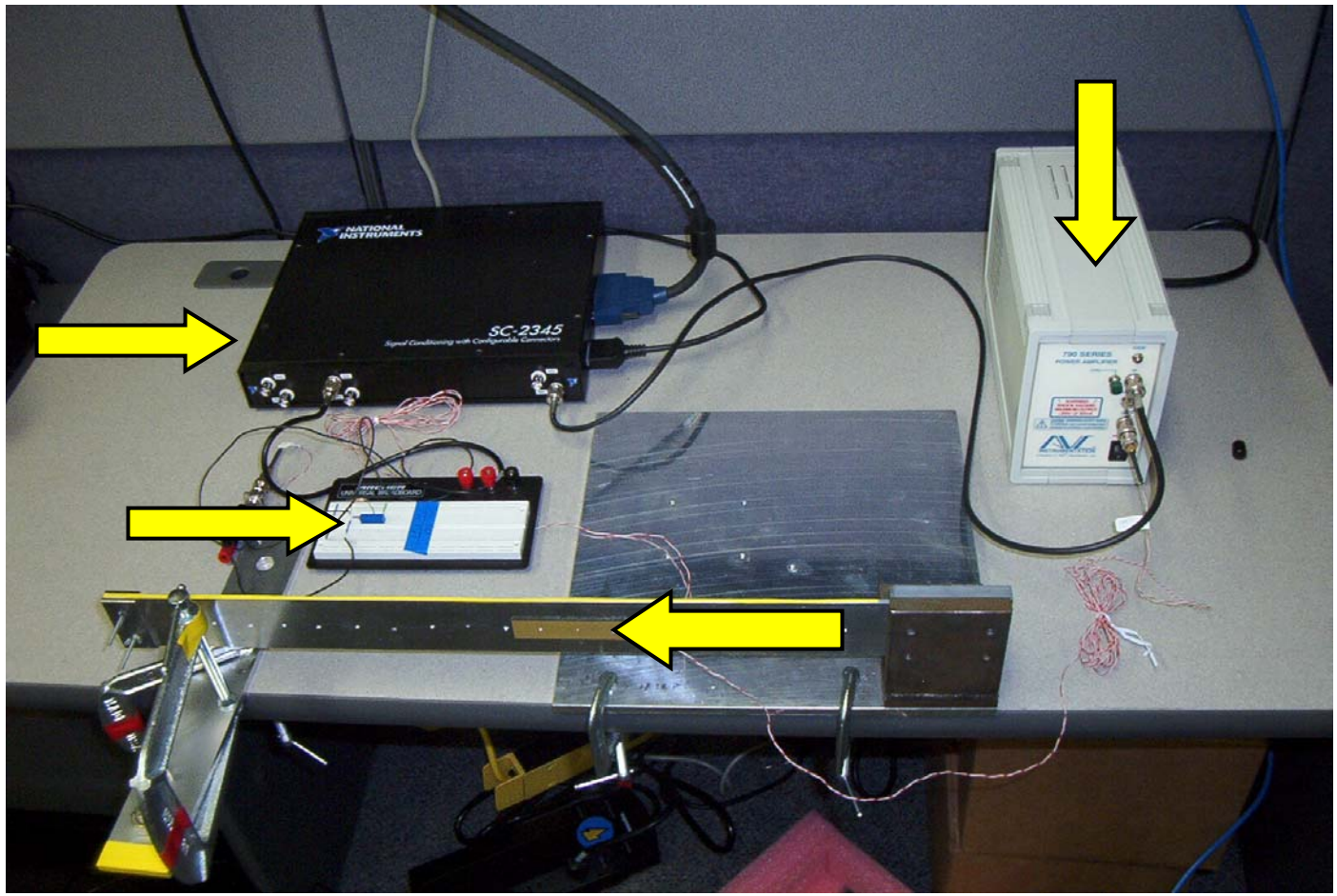




Results

The main goal is to design controllers for active vibration control of a cantilever beam





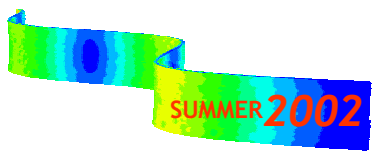
We must first examine the system behavior

We evaluate the system in three ways:

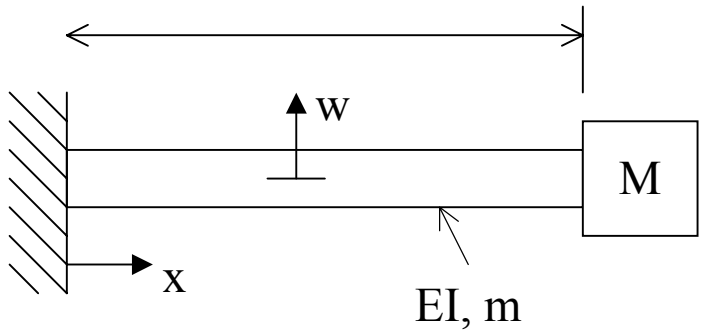
- Analytical
- Finite Element
- Experimental

For each of three end mass conditions

- No end mass (nominal)
- 65-gram end mass
- 130-gram end mass



System Behavior: Analytical



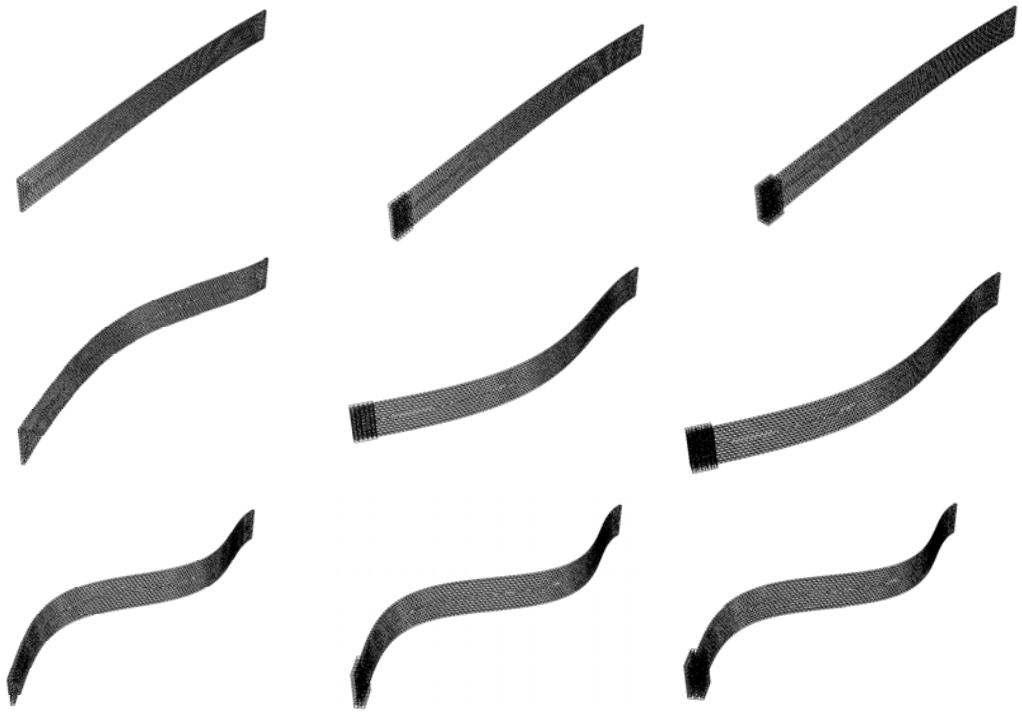
$$\mathrm{EI}\beta^3\left(1+\cosh\beta\ell\cos\beta\ell\right) + \omega^2\mathrm{M}\left(\sinh\beta\ell\cos\beta\ell+\cosh\beta\ell\sin\beta\ell\right) = 0$$

Characteristic Equation

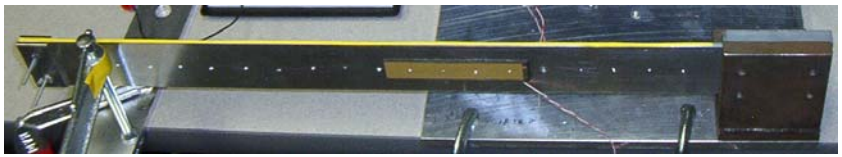
, where $\beta^4 = \frac{m}{\mathrm{EI}}\omega^2$

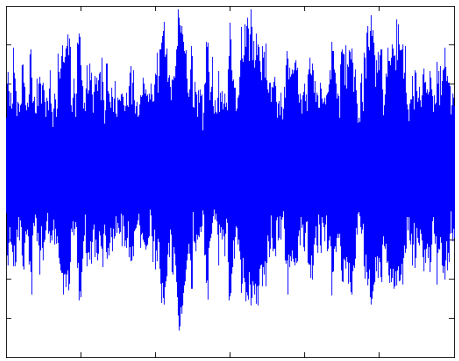
Abaqus is used for FEA

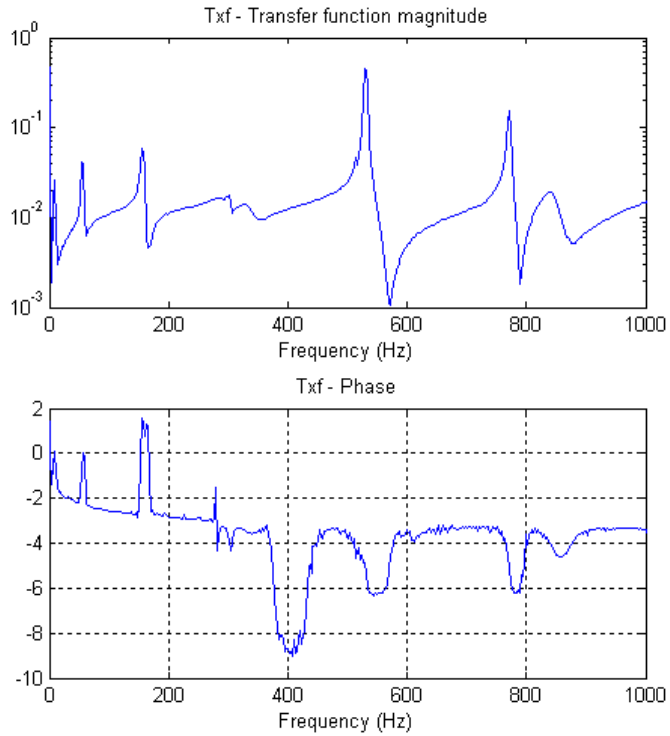
An FE model is useful for observing mode shapes and predicting natural frequencies.



FFT is used to determine frequencies



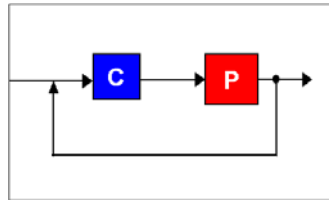


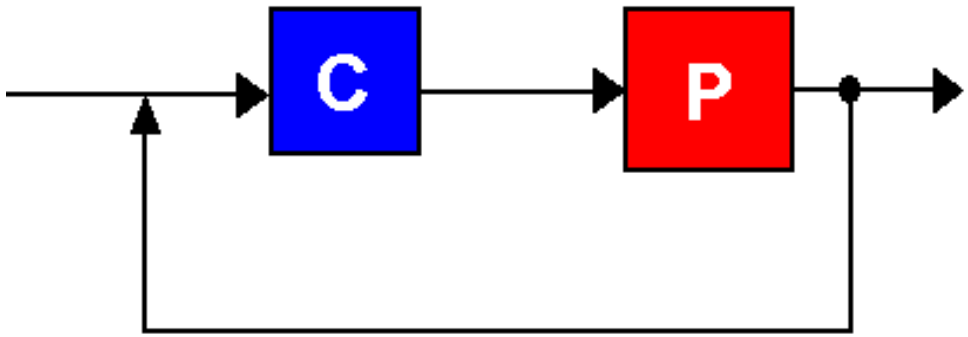


We compare the various methods

f (Hz)	Analytical	Finite Element	Experimental
No end mass			
f_{n1}	9.11	10.0	9.31
f_{n2}	57.1	62.8	55.0
f_{n3}	160	176	157
Med. end mass			
f_{n1}	4.87	7.20	6.56
f_{n2}	43.2	52.8	44.9
f_{n3}	133	157	138
Heavy end mass			
f_{n1}	3.71	5.91	5.34
f_{n2}	41.8	50.2	42.6
f_{n3}	132	132	134

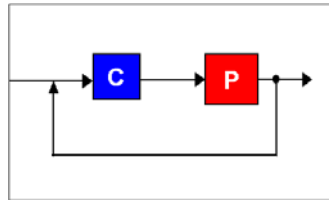
Control Methods





- PID
- LQG
- PPF

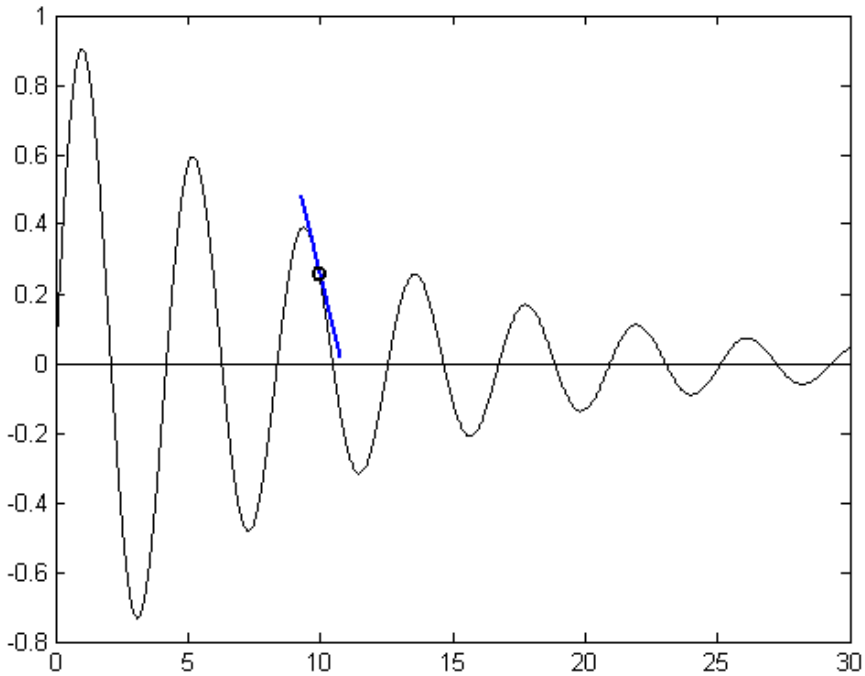
PID is simple and easy to use



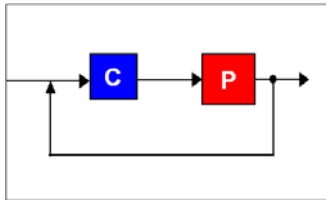
PID: Proportional, Integral, Derivative

$$u = K_P e + K_D \dot{e} + K_I \int_0^t e dt$$

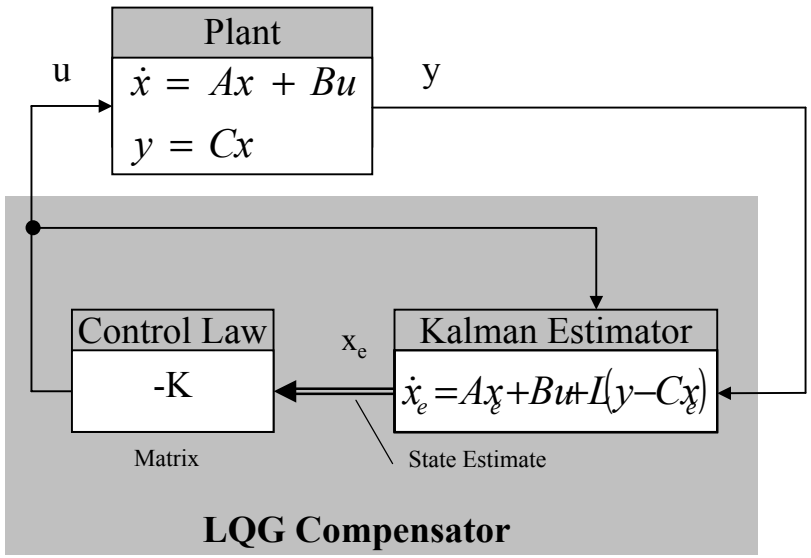
$$C(s) = \frac{K_D s^2 + K_P s + K_I}{s}$$



The advantage of LQG design is that the resulting controller is optimal



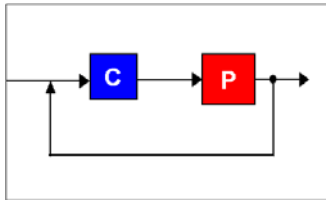
LQG: Linear Quadratic Gaussian



Control effort versus Tracking Accuracy

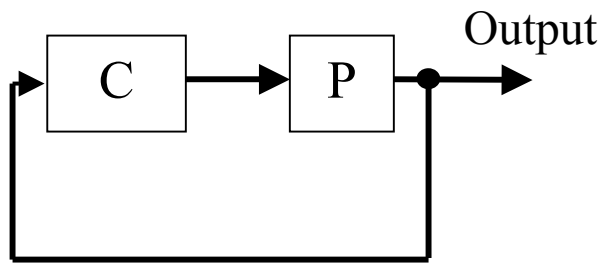
Input noise versus output noise

PPF controllers have three important parameters



PPF: Positive Position Feedback

$$C(s) = \frac{k\omega_{nf}^4}{s^2 + 2\zeta_f \omega_{nf} + \omega_{nf}^2}$$

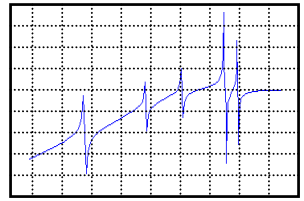


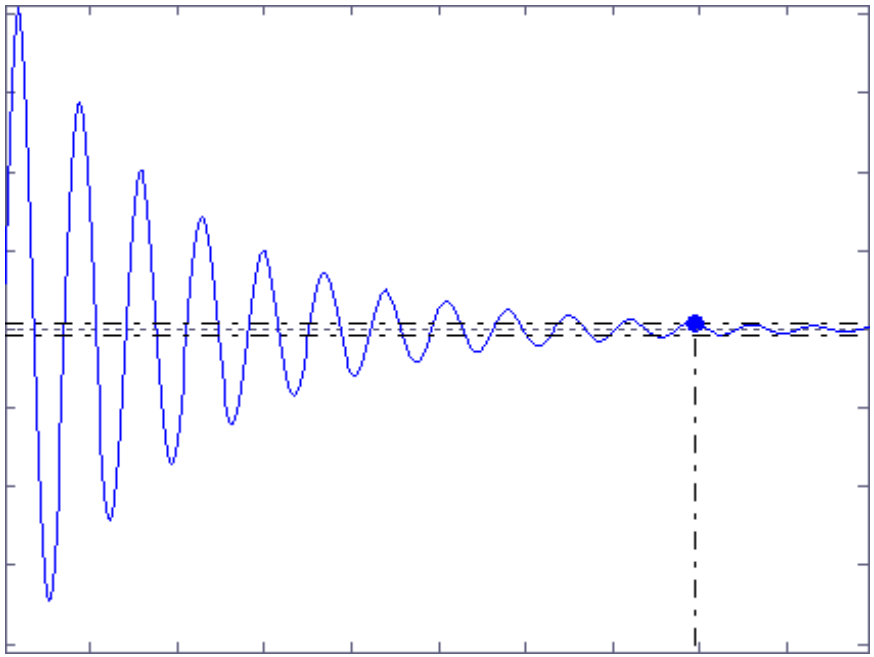
ω_{nf} Controller's natural frequency ($1.2\omega_n$ to $1.5\omega_n$)

ζ_f Controller's damping ratio

k Gain parameter of PPF

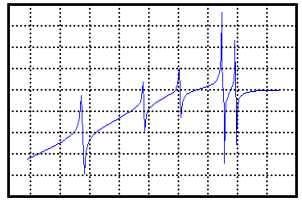
We quantify effectiveness by settling time

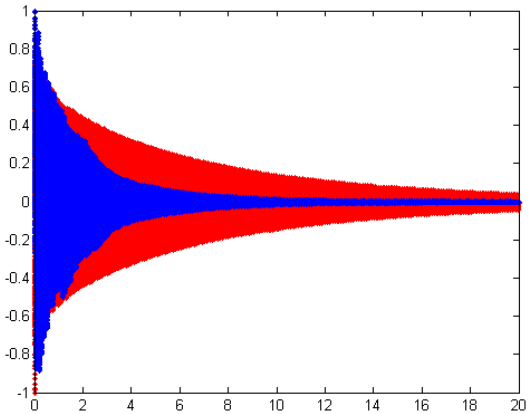




2% settling time

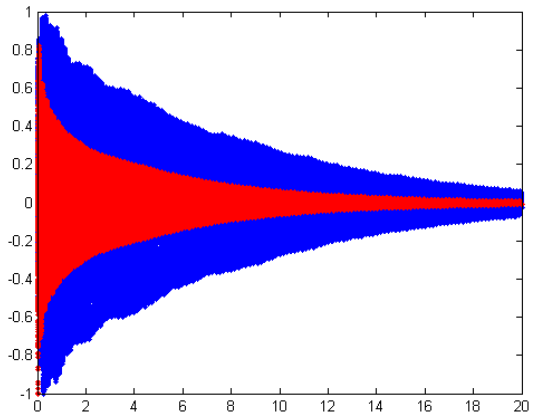
PID is effective, but not robust





nominal

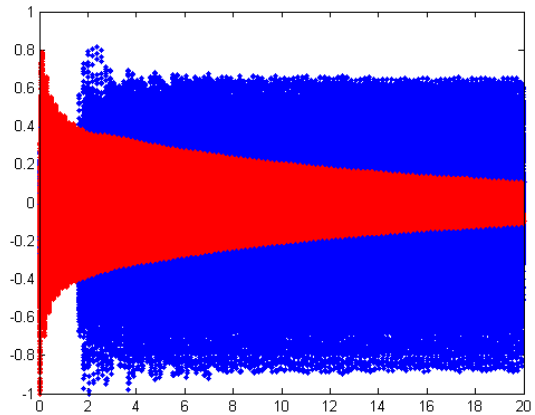
67% reduction in settling time



65-gram end mass

Uncontrolled

Controlled



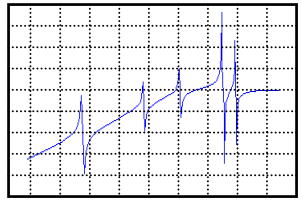
130-gram end mass

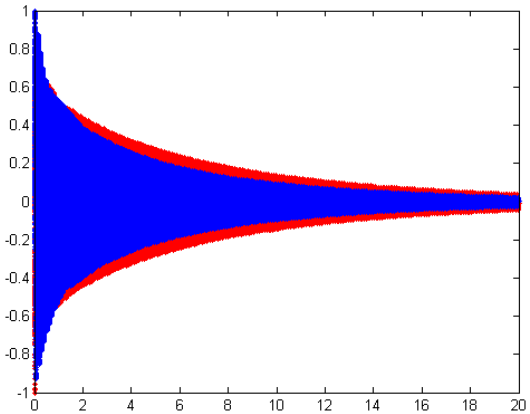
P = 100

I = 100

D = 0

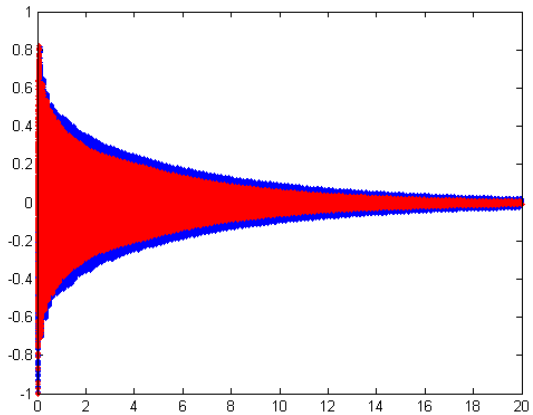
LQG is marginally effective





nominal

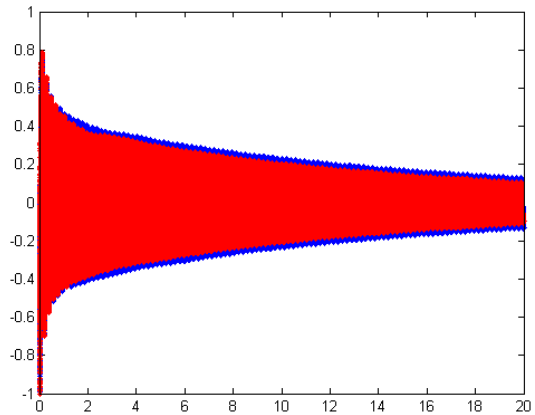
21% reduction in settling time



65-gram end mass

Uncontrolled

Controlled

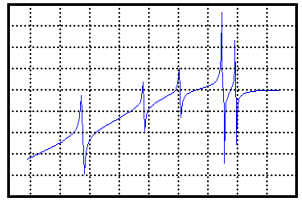


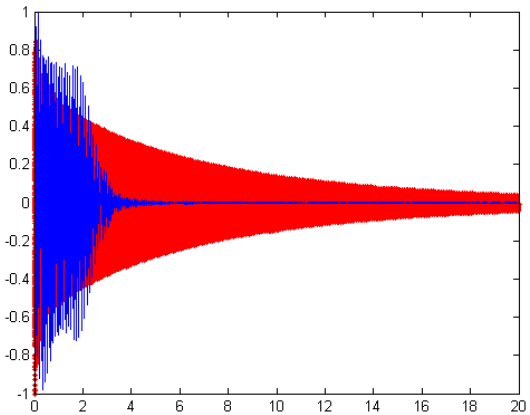
130-gram end mass

tracking performance = 40 X control effort

output noise = 40 X input noise

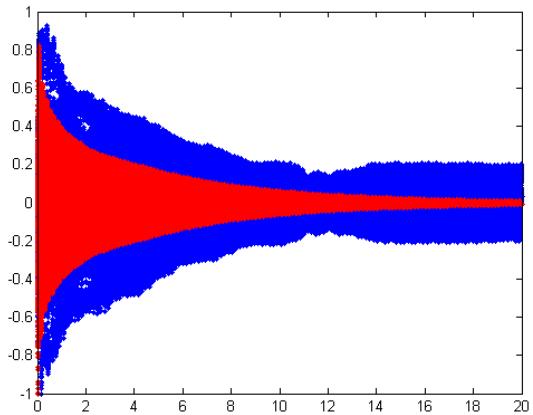
PPF is very effective, but not robust





nominal

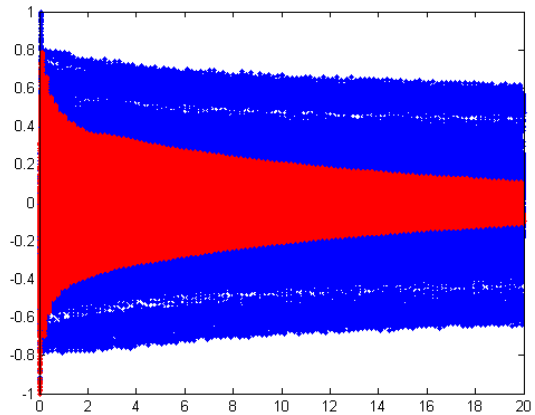
87% reduction in settling time



65-gram end mass

Uncontrolled

Controlled



130-gram end mass

$$\omega_{nf} = 11\,Hz$$

$$\varsigma_f = 0.25$$

$$k = 0.04$$

The PPF proved most effective, but no controller was robust

	Simple	Effective	Robust
PID			
LQG			
PPF			

Future Work

Apply Quantitative Feedback Theory (QFT) to PPF architecture to design for robustness.

Compare effectiveness of piezo patches that apply moment and piezo patches that apply an axial force.

Conduct similar experiments to different systems.

Evaluate the effects of saturation.

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- Vibrant Technologies (experimental modal analysis software)
- The Mathworks, Inc. (numerical analysis software)
- Hibbitt, Karlsson and Sorensen, Inc. (ABAQUS finite element software).

The PPF proved most effective, but no controller was robust

	Simple	Effective	Robust
PID			
LQG			
PPF